SEED GERMINATION IN THE EXOTIC SHRUB *CYTISUS SCOPARIUS* (SCOTCH BROOM) IN CALIFORNIA

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ABSTRACT

The germination characteristics of *Cytisus scoparius*, a weedy leguminous shrub now naturalized in California, were examined in the field and laboratory. Seed viability, longevity, and the effects of light, temperature, eliaosome removal and seed depth on germination were determined. Effects on seedling vigor of scarification by alternate immersion in liquid nitrogen and boiling water were appraised on fresh and stored *C. scoparius* seeds. Both fresh and stored seeds of a Sierra Nevada foothill population were found to be 98% viable, but >65% of *C. scoparius* seeds had an impervious seed coat that delayed germination for months or years. Permeable seeds emerge most successfully from the top 2 cm of soil, and none emerged from below 8 cm. Germination occurred at 4–33°C, maximally at 18–22°C. Heat of >150°C or more for 2 min killed the seed, and temperatures >100°C for 1 min increased susceptibility to fungal pathogens. Temperatures of 65°C for 2 min significantly increased germination and did not decrease fungal resistance. Eliaosome removal had no significant effect on seed germination. Alternate immersion in liquid nitrogen and boiling water did not effect seedling vigor and was effective in scarifying fresh and stored *C. scoparius* seeds.

Cytisus scoparius (L.) Link [*Sarothamnus scoparius* (L.) Wimmer ex Koch; Scotch broom; Fabaceae] is an alien invasive shrub species introduced into California from Europe in the 1850's as an ornamental (Geickey 1957). It is now naturalized in California, currently occupying >250,000 ha both in northwest coastal and Sierra Nevada foothill regions (L. Barbe personal communication). With a lifespan of up to 17 yr in California (Rejmánek unpublished data), *C. scoparius* produces a large quantity of seeds that continue to germinate at least 5 yr after seed sources are removed (Bossard and Rejmánek unpublished data). In the Sierra Nevada foothills, seed germination is initiated in mid-to-late November by the first biologically effective rains after the summer drought and continues through the first week in May. This species is diplochorous, containing an eliaosome on the seeds that attracts ants which gather the seeds and eat the eliaosome after their initial ballistic dispersal from the parent plant in July (Wiese 1909; Bossard 1990a). It is not known if this removal of the eliaosome by ants enhances germination of *C. scoparius* seed.

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MADROÑO, Vol. 40, No. 1, pp. 47–61, 1993

C. scoparius is considered a noxious weed by botanists, conservationists and foresters in California since it aggressively displaces native plant species and makes reforestation difficult in some areas of the Sierra Nevada foothills (Andres 1979). It is equally problematic in Oregon and Canada (Miller personal communication), Australia (Waterhouse 1988) and New Zealand (Partridge 1989) where control programs have recently been instituted. Attempts to control the spread of *C. scoparius* and to remove it from areas it already occupies have met with a multitude of problems (Parsons 1973; Williams 1981; Bossard 1991; Smith and Harlen 1991). In light of the importance of germination characteristics to establishment, understanding *C. scoparius* germination traits and the range of heterogeneity of these traits is a necessary first step in creating a comprehensive management plan to control it.

This species can have an impervious seedcoat and be difficult to germinate once dried, unless it is scarified (Schopmeyer 1974; Browse 1979; Young and Young 1986). Preliminary investigations suggest alternate immersion in liquid nitrogen and boiling water is an effective means of scarifying *C. scoparius* seeds to enhance their simultaneous germination (Abdullah et al. 1989). This would facilitate obtaining even-aged cohorts of seedlings for use in basic or applied studies on this species. However, scarification treatments may effect the vigor of resultant seedlings. Further, such treatments may not effect fresh and stored seeds in the same way (Mayer and Poljakoff-Mayber 1982).

Here I discuss studies pertaining to *C. scoparius* seeds and their germination which had the following goals: to ascertain seed viability and longevity in the field; determine the effects of light, temperature, seed depth, and eliaosome removal on germination; and to further examine the effects of alternate immersion in liquid nitrogen and boiling water as a means of scarifying *C. scoparius* seeds.

Methods

Study Site

The field research site was a 2 ha area of the Eldorado National Forest (ENF), Eldorado County, California, dominated by *C. scoparius* interspersed with *Pinus ponderosa* Dougl. and (in spring) patches of annual grasses and forbs. The pines were planted 20 yr ago for reforestation. The area is 4 km east of the Georgetown Ranger Station in the northern yellow (Ponderosa) pine forest as described by Küchler (1988) at an elevation of 1067 m, with slopes of 1 to 9%. Soil is Maymen rocky loam 10–65 cm deep. Annual precipitation averages 142 cm with a range of 69–290 cm per year; almost no rain occurs from May to November. Total precipitation in 1987, 1988, and 1989 was 117 cm, 74 cm, and 110 cm, respectively (El-

dorado National Forest District Headquarters, Eldorado County, California).

Experimental Methods

All seeds used in these experiments came from bulk samples collected by hand at ENF. Seeds were collected from mature pods of *C. scoparius* shrubs one week after ballistic dispersal ensued. Seeds were collected 29 June, 1987 and stored at 4°C in opaque glass jars (stored seed) or collected 8 July, 1988 and used the next day (fresh seed).

1. Speed viability and moisture content. Viability of seeds stored 6, 9, and 12 months and fresh seeds from ENF was assessed via tetrazolium red tests (Mackey 1972; Moore 1972). Seeds were knicked, soaked 3 hr at 22°C, immersed in tetrazolium red for 8 hours at 22°C, then bisected with a razor blade and examined for staining. Moisture content of three groups of 200 seeds was tested via the low temperature method (Thomson 1979).

2. Seed longevity in the soil. To estimate the amount of seed germinating from a given year's seed crop over time, 1000 *C. scoparius* seeds collected June, 1987 were placed in each of eight 1 × 12 × 12 cm mesh bags. Four of the bags were placed on the soil surface and four others were placed 4 cm under the soil surface at the ENF research site in July, 1987. The seed bags were covered with a 60 × 60 × 30 cm exclosure made of 1.5 cm mesh chicken wire. In January, March, and May, 1988, 1989, 1990, the germination status of the seeds was recorded and the germinated seeds were removed from the bags.

3. Response to depth of planting. To ascertain the effect of planting depth on seedling emergence *C. scoparius* seeds stored 6 months were planted in 15 × 15 × 15 cm plastic pots filled with University of California, Davis, sandy loam greenhouse mix soil at depths of 0, 1, 2, 4, 6, 8 and 10 cm, then placed in a greenhouse with a temperature range of 20–25°C. Of the 20 seeds per treatment those seeds emerging were counted weekly for 8 weeks. There were three replicates of 20 seeds at each depth. At ENF in November, 1987, a 12 cm deep vertical walled trench was dug and 15 seeds were inserted 2 cm into the side of the trench in two places at each of the same depths used in the greenhouse study, then the trench was filled.

4. Response to temperature. The following methods apply to the response to temperature experiment and also to experiment 5 described below. For each pre-germination treatment, 25 stored seeds were plated in a 10 cm Petri dish lined with 2 circles of Whatman No. 1 filter paper kept moist with distilled water. Petri dishes were

placed in a growth chamber with the following settings: 15 L/9 D hr photoperiod (120 μmol m^{-2} sec^{-1}) and 23/16°C thermoperiod conditions comparable to those found in the field during the latter portion of the *C. scoparius* germination season (Bossard 1990b). The number of seeds imbibed (scored as a >50% increase in seed diameter) and the number of seeds germinated (scored as radicle protrusion of >2 mm) was recorded every 2 days the first week and every 3–4 days thereafter. In cases where fungal infection of the seeds occurred, the level of infection and fate of the seeds were recorded.

Temperature effects on germination were determined using a temperature step gradient bar (Grime et al. 1981) with temperatures set at 5, 10, 14, 18, 22, 26, 30, and 33°C. Seeds stored 7 months were used in this experiment. Each of two pre-germination treatments was replicated in four Petri dishes. Treatments were: 1. controls given no pre–germination treatment; 2. seeds alternatively immersed in boiling water and liquid nitrogen. In this treatment seeds were placed in cheese cloth bags and dipped for 3 seconds in boiling water then 15 seconds in liquid nitrogen. This alternation was done twice followed by just one second in boiling water to thaw the bag (hereafter hot/cold).

5. Response of fresh and stored seeds in Petri dishes to various pre-germination treatments. The effects on germination of exposure to light, removal of eliaosome, heat, and hot/cold scarifying of seeds were examined in two studies done June–August, 1988. Both seeds stored 11 months and fresh seeds were utilized for this experiment. The treatments were:

(1) controls (no pre-germination treatment, eliaosomes on),
(2) dark (each Petri dish was completely wrapped in aluminum foil and opened briefly for counting of germinants under a low intensity of green light),
(3) light (each Petri dish left exposed to growth chamber lights),
(4) eliaosome off (entire eliaosome removed with a tweezers from stored seed germinated in light),
(6) 65°C-60s, 65°C-120s (stored seeds placed in 65°C oven for 60 and 120 sec and germinated in light),
(7) 100°C-60s, 100°C-120s (stored seeds placed in a 100°C oven for 60 and 120 sec and germinated in light),
(8) 150°C-60s, 150°C-120s (stored seeds placed in 150°C oven for 60 and 120 sec and germinated in light),
(9) 200°C-60s, 200°C-120s (stored seeds placed in 200°C oven for 60 and 120 sec and germinated in light),
(10) hot/cold (as described above).

The oven was modified with sheet metal and aluminum foil so seeds could be introduced through a 2 cm by 12 cm opening while

allowing minimal heat escape. Duration of heat treatments was intended to simulate the duration of change in temperatures in a flash fire (Floyd 1966) typical of prescribed burns, since prescribed burning is one method expected to be used to remove invasive populations of *C. scoparius*. Maximum temperatures when measured at 2 cm below the soil surface during a prescribed burn at Eldorado National Forest ranged from 59°C to 152°C depending on the fuel load (Bossard unpublished). Temperatures chosen for this study approximated this range and were reported in other studies to stimulate germination of legumes in the field (Quinlivan 1961, 1966; Floyd 1966; Martin et al. 1975; Shea et al. 1979; Auld 1986). Treatments were replicated in four Petri dishes. Seeds not germinating were tested for viability via tetrazolium red tests (Mackey 1972; Moore 1972).

6. Response of seeds in soil to heating, alternating temperature scarification. To assess the vigor of the seedlings, the following experiment was done using seed stored 9 months. Twenty-five seeds each were placed in 15 × 15 × 15 cm plastic pots filled with University of California, Davis, sandy loam greenhouse mix soil, then covered with 1.5 cm soil. Four previously described pre-germination treatments were used:

(1) control (no pre-germination treatment),
(2) bake 65°C (placed in 65°C oven for 60 seconds),
(3) bake 100°C (placed in 100°C oven for 60 seconds),
(4) hot/cold

All pots were placed in the growth chamber with conditions as described previously. There were four replications of each treatment. The number of emerged seedlings was recorded for each pot every two days during the first week and every 3–4 days thereafter.

Statistical analysis. Analysis was done using multiple regression and ANOVA in Statview 512+. Data on the number of seeds germinating were analyzed after angular transformation. Multiple mean comparisons were conducted using Scheffé's test (Zar 1984).

Results

Seed viability and moisture content. Ninety-eight percent of the 6, 9 and 11 month stored and freshly collected seeds were found to be viable by the tetrazolium red test. Seeds stored 6 months had a moisture content of 10.2%, while fresh seed had a moisture content of 14.1%.

Seed longevity in the soil. There was no significant difference in the proportion of seeds germinating at or 4 cm below the soil surface (Table 1). About ⅔ of the seeds from the 1987 seed crop germinated

TABLE 1. FIELD GERMINATION OF *CYTISUS SCOPARIUS* SEEDS. n = 4 for each treatment.

Elapsed time from placement	On surface		4 cm below soil surface	
	Seeds germinated	Seeds remaining ungerminated	Seeds germinated	Seeds remaining ungerminated
6–11 months	65 ± 12%	35 ± 12%	64 ± 9%	36 ± 9%
18–23 months	20 ± 4%	15 ± 4%	24 ± 4%	11 ± 4%
30–35 months	10 ± 3%	5 ± 2%	4 ± 2%	7 ± 3%

in the field during the first year. By the end of the second germination season, <15% of the seed remained ungerminated.

Response to depth of planting. The largest proportion of seeds emerged from depths of 1 and 2 cm. In the greenhouse, there was little emergence of seed planted 8 cm or below and only 50% emergence from plantings at 6 cm (Fig. 1). At ENF, no seeds emerged below 6 cm.

Response to temperature. Some germination occurred at all temperatures for hot/cold and control seeds within 4 wk (Figs. 2 and 3). The hot/cold treatment increased rate and final germination percentage when compared to the controls. Hot/cold treatment seeds showed maximum germination at 18–22°C, whereas maximum germination for control seed occurred at 22–26°C.

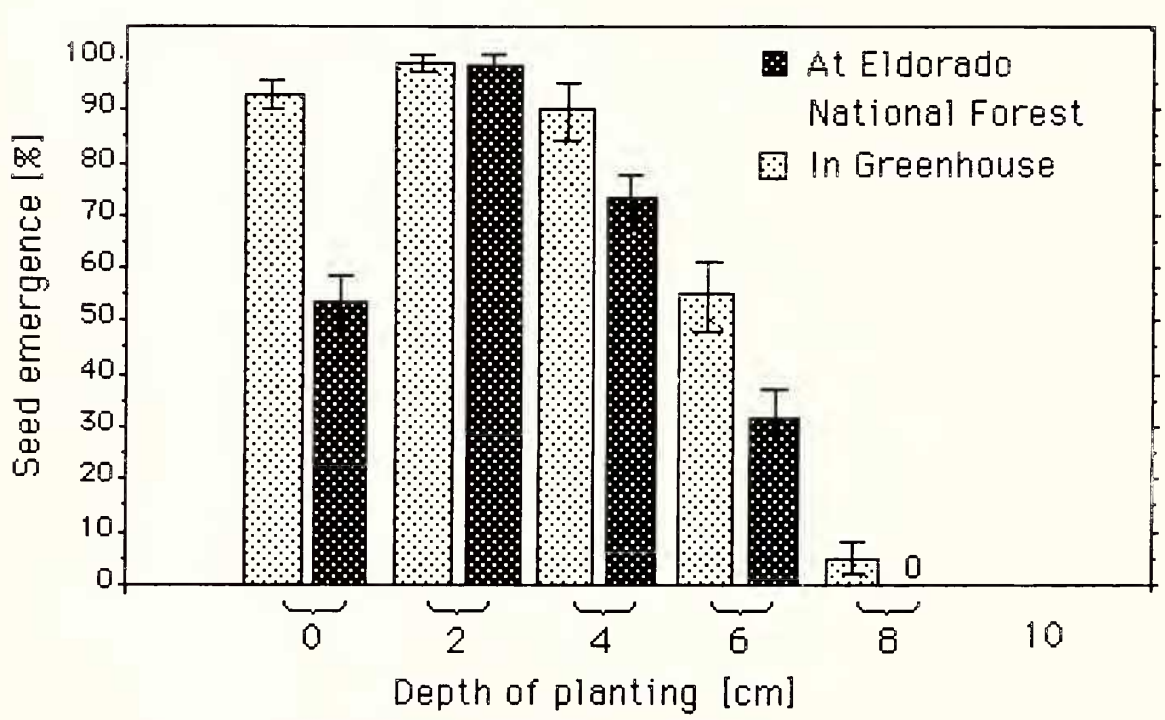

FIG. 1. The proportion of *Cytisus scoparius* seeds emerged from various planting depths in sandy loam in the green house and at Eldorado National Forest in naturally occurring rocky loam. Bars show 95% confidence intervals.

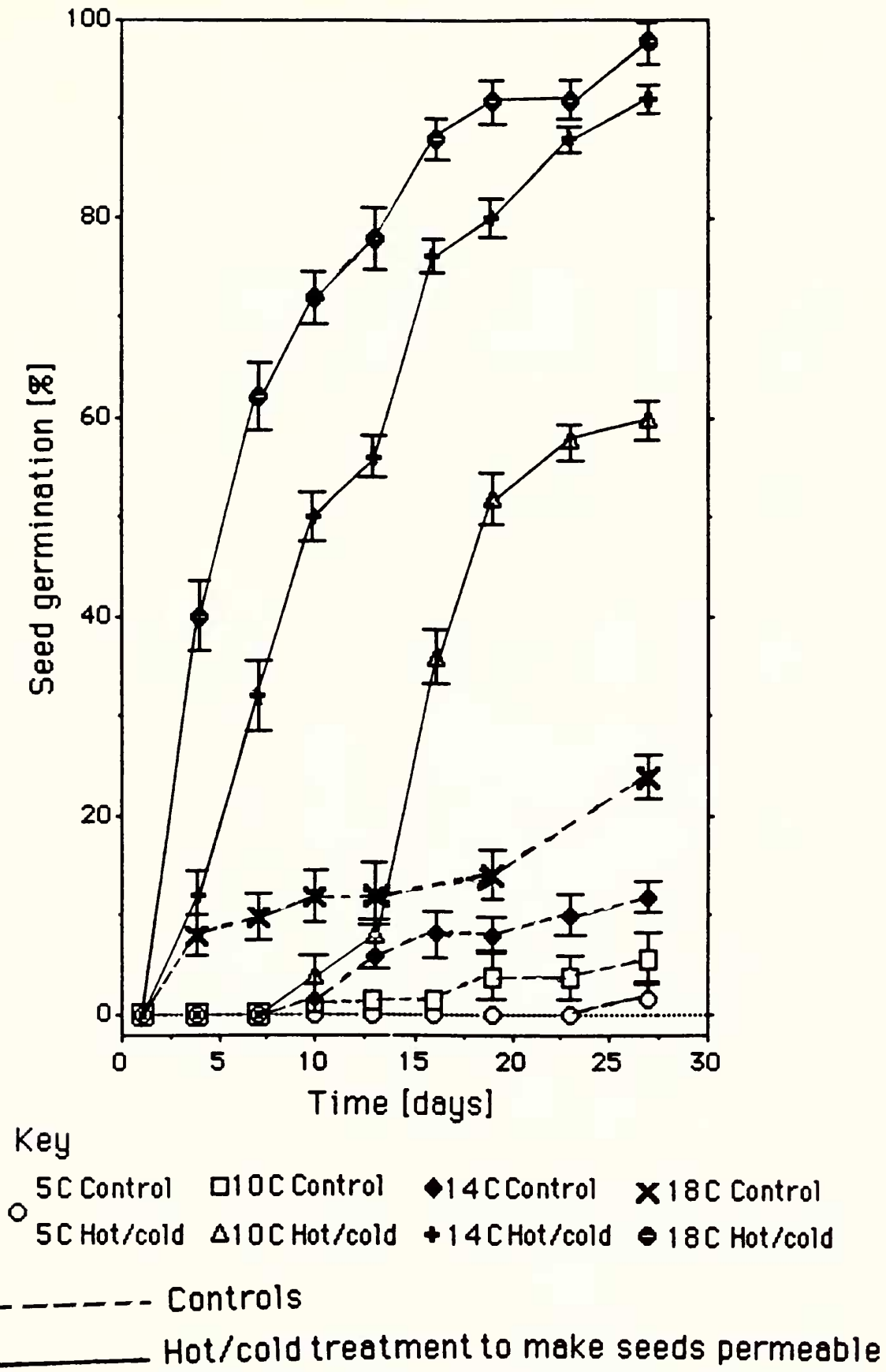

FIG. 2. The proportion of *Cytisus scoparius* seeds germinating over 28 days at various constant temperatures between 5 and 18°C. Bars show 95% confidence intervals.

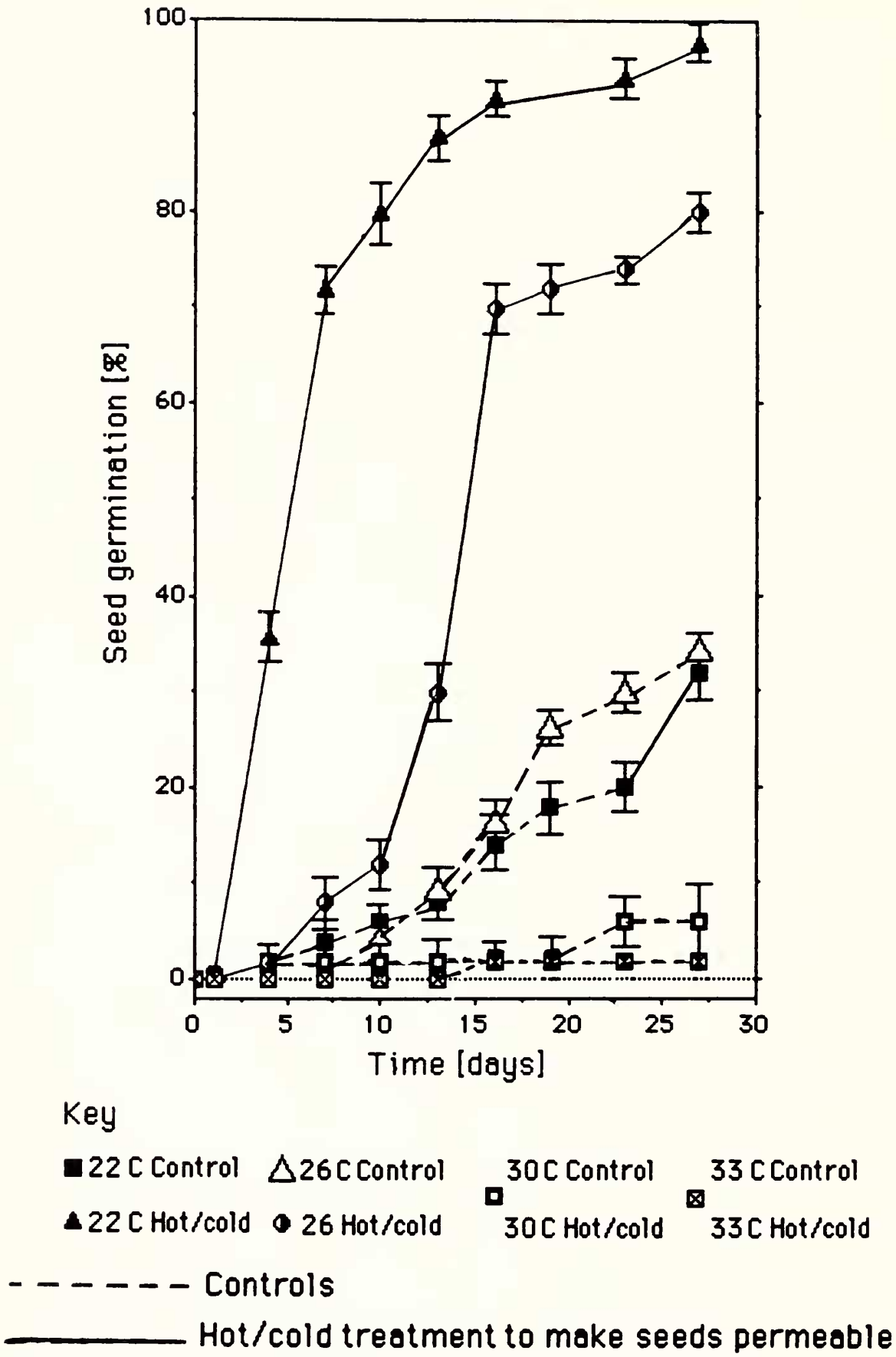

FIG. 3. The proportion of *Cytisus scoparius* seeds germinating over 28 days at various constant temperatures between 22 and 33°C. Bars show 95% confidence intervals.

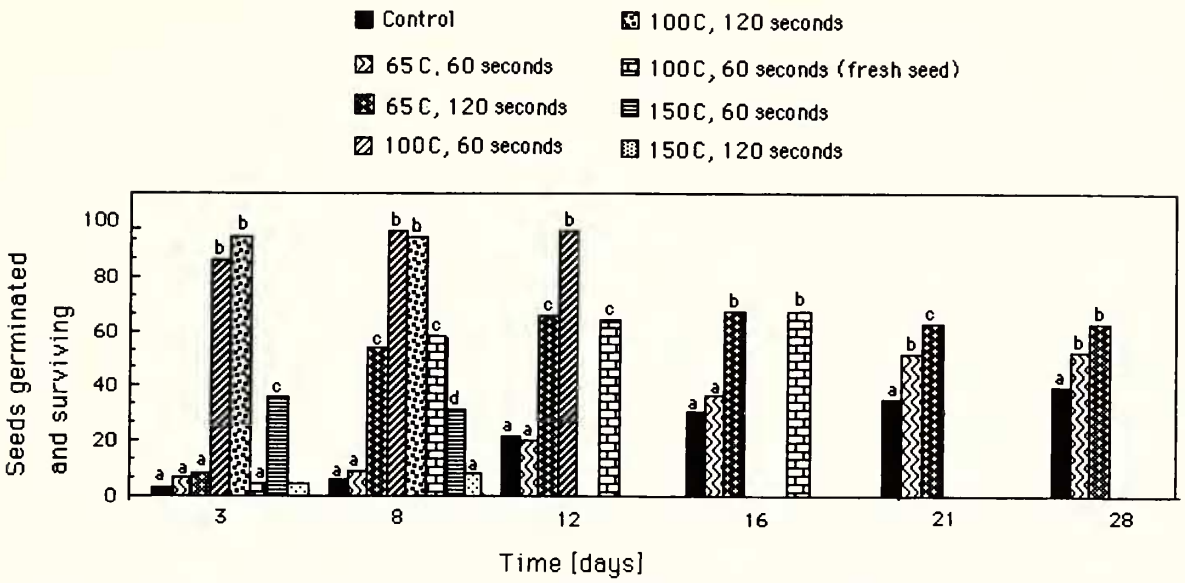

FIG. 4. The proportion of *Cytisus scoparius* seeds germinating and surviving after various heat treatments. For each date means with the same letters are not significantly different at the 0.05 level.

Response of fresh and stored seed in Petri dishes to various pre-germination treatments. An ANOVA repeated measure analyses of independent variables, eliaosome removal and date on the dependent variable, number of seeds germinated in 32 days, showed eliaosome removal had no significant effect ($F = 0.92$; $P > 0.05$).

The effect of light on seed germination varied somewhat with the age of the seeds but the differences were not statistically significant (Table 2). At least 34% of control seeds germinated regardless of light conditions. The hot/cold treatment elicited significantly more germination on stored seed than on fresh seed. It resulted in the highest proportion of seeds germinating and did not diminish the vigor of the seedlings. Heating the seeds stimulated significantly more germination in stored than fresh seeds, but in all heat treatments (except 65°C) seedlings died of fungal infections by the 15th day of incubation (Fig. 4). Seeds baked 60 and 120 sec at 200°C did not germinate. Tetrazolium red tests revealed 100% of ungerminated control and 65°C heated seed was viable. One hundred percent of ungerminated 150°C seed heated 120 seconds and all ungerminated 100°C and 200°C heated seed was not viable. Ninety-two percent of ungerminated 150°C seed heated 60 seconds (62 of 64 seeds) was not viable.

Response of seeds in soil to heating and alternating temperature scarification.—For seeds planted in soil, the hot/cold pre-treatment was the most successful in increasing emergence (Fig. 5). Examination of the pots containing 100°C heat treated seeds after seven days revealed that 96% of the seeds had germinated, but died of fungal infections before emerging.

TABLE 2. THE PROPORTION OF *CYTISUS SCOPARIUS* SEEDS GERMINATING AND SURVIVING AFTER VARIOUS PRE-GERMINATION TREATMENTS. An ANOVA revealed treatment means with + are significantly different at the 0.05 level, with ++ significantly different at the 0.01 level using Scheffé's tset. # Seedlings died from fungal infections in these two treatments.

Treatment	Seeds germinated [mean %] 12 days after plating	Range	Treatments 1	2	3	4	5	6	7	8	9	10
(1) Control, stored, light	14	12–16										
(2) Control, stored, dark	17	16–20										
(3) Control, fresh, light	30	24–36										
(4) Control, fresh, dark	19	16–24										
(5) Bake 100°C, stored	97	96–100	++	++	++	++						
(6) Bake 100°C, fresh	69	68–72	++	++	++	++	+					
(7) Hot/cold, stored, dark	82	80–88	++	++	++	++						
(8) Hot/cold, fresh, dark	75	72–80	++	++	++	++	+					
(9) Hot/cold, stored, light	84	80–88	++	++	++	++						
(10) Hot/cold, fresh, light	68	68–68	++	++	++	++	+					

Treatment	Seeds germinated and surviving 32 days after plating [mean %]	Range	Treatment 1	2	3	4	5	6	7	8	9	10
(1) Control, stored, light	34	32–36										
(2) Control, stored, dark	39	36–40										
(3) Control, fresh, light	50	48–52										
(4) Control, fresh, dark	39	36–44										
(5) Bake 100°C, stored	6#	4–8	++	++	++	++						
(6) Bake 100°C, fresh	6#	4–8	++	++	++	++						
(7) Hot/cold, stored, dark	95	92–96	++	++	++	++	++	++				
(8) Hot/cold, fresh, dark	82	80–84	++	++	++	++	++	++	+			
(9) Hot/cold, stored, light	98	96–100	++	++	++	++	++	++		+		
(10) Hot/cold, fresh, light	89	88–92	++	++	++	++	++	++			+	

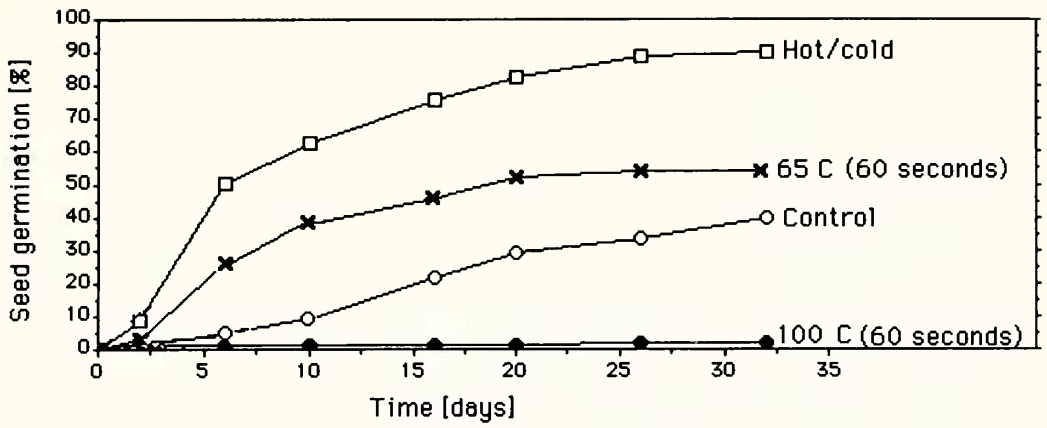

FIG. 5. The proportion of *Cytisus scoparius* seeds emerged from the soil after receiving various pre-germination treatments.

DISCUSSION

Almost 100% viability, in both fresh seed and seed stored up to 2 yr, was found in this study. Although possessing high viability 60% of *C. scoparius* seeds from ENF contain impervious seed coats which prevent germination in field or laboratory until these seeds become permeable. This species' seeds have a range of phenotypic expression of both within- and between-year germination. While 40% of the seeds can germinate immediately upon dispersal and another 25% germinated sometime during the first year after deposition, at least 7% remain ungerminated after three years in the soil allowing the development of a large seed bank. Variability in the duration between seed deposition and germination provides *C. scoparius* with considerable flexibility for coping with the intra- and inter-yearly fluctuations in precipitation and temperature typical of California's Mediterranean climate.

In the laboratory, no more than 50% of unscarified seed of the ENF population germinated in any of the experiments within 32 days. This contrasts sharply with the findings of Grime et al. (1981) on germination of an English population of *C. scoparius* in which 73% of freshly collected seed and 90% of the seed stored 6 months at 5°C in jars germinated in 15 days.

Differences in the germination characteristics between seeds of these two populations could be caused by preconditioning, i.e., differences existing in the environments under which the seeds matured (Baskin and Baskin 1973), post-dispersal conditions, or genetic differences. Aitken (1939) found the degree and duration of hardseededness in several Fabaceous species depended on the amount of time existing for deposition of suberized materials in the seed coat (Aitken 1939; Brown 1955) and the degree of dehydration attained by that seed (Aitken 1939; Hyde 1954; Quinlivan 1968; Williams and Elliot 1966). The degree of desiccation experienced by the seeds of the California population, where relative humidity in the summer de-

clines to 10%, is considerably more than that experienced by the English population exposed to a minimum relative humidity of 54%. Since the European progenitors of the ENF population arrived in the California foothills >120 yr ago, it is possible ecotypic differentiation has occurred. Researchers on other leguminous species have reported significant differences in hardseededness for different varieties of *Melilotus alba* (Stevenson 1937) and *Trifolium repens* (Burton 1940). However as Baskin and Baskin (1973) and Quinn (1977) assert, when environmental explanations for the variations in seed germination characteristics exist, no genetic basis for those differences should be assumed without further research. Consequently, at this time the exact basis for differences in seed germination responses between populations in California and England cannot be ascribed.

Germinating *C. scoparius* seeds emerged most successfully from the top 2 cm of soil, although a few seeds gave rise to emergent seedlings from a depth of 6 cm in the field and even 8 cm in the sandy loam soil used in green house trials. Seeds found in abandoned *Aphaenogaster occidentalis* nests below 6 cm depth (Bossard 1990b) are therefore likely to represent lost genets of *C. scoparius.* Auld (1986) observed a similar situation for *Acacia suaveolans* in Australia; maximum field germination depth was 6 cm in this species, but seeds in ant nests were often as deep as 10 cm.

Temperatures provide minimal barriers to germination of *C. scoparius* seeds. The broad range of temperatures at which seeds from the ENF population can germinate may partially explain the ability of this woody weed to establish in many geographic areas with a variety of climates, and they are consistent with the long germination period observed for *C. scoparius* in the field at ENF. Almost 100% germination was attained in constant temperature conditions after pre-germination treatments which made the seeds permeable. Apparently, it has no physiological requirement for a cold period or variable day/night temperature for germination such as that found by Hagon (1971) in *T. subterraneum.*

The hot/cold treatment successfully enhanced germination of *C. scoparius* in Petri dishes and in soil without decreasing the vigor of the resultant seedlings. The greater enhancement of germination of stored seed than fresh seed by this technique is likely due to the greater level of desiccation existing in the stored seed. This is a useful method for scarifying this seed.

The findings of this study add credence to Baskin and Baskin's (1989) proposition that temperature is the most important environmental factor in the breakdown of the leguminous strophioles that maintain seed impermeability under natural conditions. Germination was significantly lower ($P < 0.001$) in unscarified seeds stored at a constant 4°C for seven months and then kept at constant op-

timum temperature on the temperature gradient bar than for unscarified seed exposed to the fluctuating temperatures in the field for 9 months. Daily range in summer ground temperature at the research site was 30–55°C day and 15 to 25°C night (Bossard unpublished data), comparable to daily fluctuations of summer temperature found by Quinlivan (1961, 1968) to make small herbaceous legume seeds permeable in the field.

Heating seeds to temperatures between 65 and 100°C stimulated germination. While seeds heated to 100°C for 60 or 120 seconds had almost 100% germination, all seedlings from that treatment and those from the 150°C heat treatment died from fungal infections by the fifteenth day after treatment. Parker and Kersnar (1989) found that germination of *Cytisus monspessulanus* seeds also was enhanced by 100°C heat for 60 sec but that the resulting seedlings suffered an increased rate of mortality. Temperatures of 150°C even for 60 sec made the majority of *C. scoparius* seeds non-viable. Temperatures of 65°C for 2 min significantly increased germination compared to that of controls (62% versus 42%) and did not increase the seedling mortality rate from fungal infection.

These results indicate that prescribed burns of areas infested with these shrubs could greatly decrease the number of seeds on and in the soil if burns are done under conditions that maximize soil heating so as to flush germination of seeds prior to the summer drought period at ENF. Research on the feasibility of depleting *C. scoparius* seedbanks by prescribed burning is in process.

Acknowledgments

This Research was supported in part by the Hardman Foundation For Evolutionary and Conservation Research and The California Native Plant Society. I am grateful to Dr. Marcel Rejmánek for advice on the analysis of this project. The field assistance of Robert Powell, Kimberly Chew, Honza Rejmánek, Eileen Lee, and Carolyn Way, and the cooperation of Eldorado National Forest personnel is much appreciated. I thank Drs. Marcel Rejmánek, Michael Barbour, Maureen Stanton, V. Thomas Parker and Kenneth Thompson for comments on the manuscript.

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(Received 3 Feb 1992; revision accepted 8 Jul 1992.)